Human Factors and Information Operation for a Nuclear Power Space Vehicle

Anna C. Trujillo
NASA Langley Research Center
MS 152, Hampton, VA 23681
Tel: (757) 864-8047, Email: a.c.trujillo@larc.nasa.gov

S. Alenka Brown-Van Hoozer, Ph.D.
Oak Ridge National Laboratory
Cognitive Technology and Advanced Concepts
Tel: (865) 241-6234, Email: brownvanhosa@ornl.gov

Abstract – *This paper describes human-interactive systems needed for a crewed nuclear-enabled space mission. A synthesis of aircraft engine and nuclear power plant displays, biofeedback of sensory input, virtual control, brain mapping for control process and manipulation, and so forth are becoming viable solutions. These aspects must maintain the crew's situation awareness and performance, which entails a delicate function allocation between crew and automation.*

I. INTRODUCTION

Nuclear power for propulsion is once again becoming a NASA priority. The new NASA administrator states that "[p]ower and propulsion alternatives are needed to conquer [distance faster] so as to allow nearer results than are possible with existing capabilities." [1] For crewed nuclear-enabled space missions, crews will have two very important roles – as pilots and as nuclear reactor operators. Fortunately, a considerable amount of research has been conducted in both areas providing information that can be integrated for space flight applications. Research and applications described in this paper address the human-interactive systems advances in the aircraft and nuclear power plant industries involving such areas as adaptive systems and display technologies. How these and other human research applications should be merged for nuclear-powered space missions is the focus of this paper.

II. AFFECTS OF FUNCTION ALLOCATION ON CREWS

Aboard any vehicle, the crew and the automation can take on several different roles depending on the situation. For the crew, these roles are as team member, commander, individual operator, and occupant.[2] For automation, these roles are as a substitute, augmenter, and aid.[2] At various times, each crewmember may behave in a particular role. In order to keep each operator engaged and situationally aware, the automation must be at a level such that the operators are frequently engaged with the system.

Levels of automation can also seriously affect crew performance and workload. For example, automation may degrade performance and situation awareness after a non-normal event, though manual control, which increases performance and situation awareness, has a cost of high workload.[3] Therefore, the balance between operator and automation allocation must be taken into consideration in any human-interactive system design.

This balance becomes especially important during non-normal situations. During a high-stressed and usually time-compressed situation, the operators must quickly and efficiently take care of any problem. If the crew is unfamiliar with the current status and recent history of the systems, then additional time may be needed to come up to speed. Therefore, function allocation during both normal and non-normal operations is an important factor in order to maintain performance and situation awareness while controlling the workload level.

One approach being researched is the adaptation of the system to how an individual mentally processes information. We know that individuals process information using the three primary modalities: visual, auditory, and kinesthetic. Depending on how these modalities are sequenced provides insight to how crewmembers will respond to specific situations. For example, preliminary results of a current research project conducted by NASA and ORNL involves identifying the general decision-making patterns of 21 airline pilots via an eye-tracking device (refer to table I). The decision-making patterns generated from a neuro-physiological base are now being correlated to those areas of the cockpit that each pilot focuses on most and least frequently.

It is from these types of studies that more adaptive human-interactive systems are to be generated to increase performance and situation awareness.

Table I – Information Processing Order

Information Acquisition Order	Number of Pilots	%
Visual – Auditory – Kinesthetic	10	48%
Auditory – Visual – Kinesthetic	6	28%
Kinesthetic – Visual – Auditory	3	14%
Visual – Kinesthetic – Auditory	2	10%

III. CREW DUTIES

The primary function of any crew is to perform an objective successfully, and this will be no different for the nuclear power reactor aboard a space vehicle. On aircraft, the crew must perform the following functions: flight management, communications management, systems management, and task management.[4] On a space mission, the crew's duties will primarily be to monitor the situation, and systems and task management. This will require the ability for a cursory glance to make sure everything is running optimally because of the complexity of the systems. At any time the crew must be able to access more detailed information in a manner that adapts to how each individual processes information from a system that provides various decision outcomes in a visual imaging format. If there is a problem, the crew must be notified of its severity and function(s) affected along with its affects on the overall mission. Providing the crew a human-interactive adaptive system that is 3D in order to contain this information will allow the crew to effectively respond to the crisis in a more timely and accurate manner. Once the problem is identified, the crew would be able to remedy the situation accomplishing a more detailed diagnosis and thorough repair of the non-normal situations.

III.A. Cursory Monitoring

Most of the time, the crew's duties are to monitor the situation. Optimally, reactors should run without problems so a human-interactive display to quickly check on reactor health is necessary. In the aviation industry, two excellent examples are E-MACS[5,6] (fig. 1) and MSG[7] (fig. 2), which is currently being tested. These interactive displays will let operators know if something is not in its expected normal range. It is proposed that systems of this nature would be enhanced to project 3D imaging of problems and display a set of decision strategies that could be used by the crew. These decision strategies would be registered at the console via a projected image, and move with the individual as they traverse to various sections of the control room.

Because of the vast amount of information the crew must monitor, the information will be preprocessed by the automation in order to keep workload down at a reasonable level. However, the operators must maintain their situation awareness since this will probably degrade with the use of an automated system.[3] The design goal of these human-interactive projected displays for mission monitoring then will be to keep the crew abreast of the mission health as a whole to include mission parameters. For example in the MSG display concept, the parameters are not limited to vehicle internal system parameters, but can also be expanded to include generated mission parameters aiding in monitoring the mission, not just the systems.

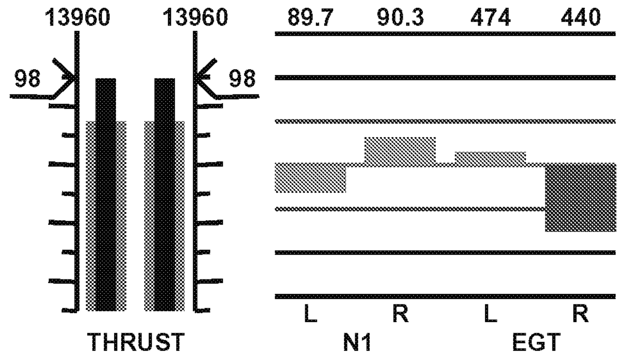
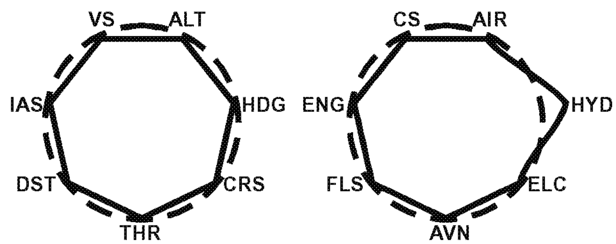


Figure 1 – E-MACS Display



ALT = altitude	AIR = pneumatic system
HDG = heading	HYD = hydraulic system
CRS = course	ELC = electrical system
THR = thrust	AVN = avionics
DST = distance	FLS = fuel system
IAS = indicated air speed	ENG = engine
VS = vertical speed	CS = control surfaces

Figure 2 – MSG Display

III.B. Detailed Monitoring

On those occasions that operators want or need detailed information, complete system information must be available in an easy to comprehend format that we propose be projected in any part of the environment that the crew desires for retrieval. As before, this format needs to adapt to how individuals process information in order to have them understand the situation more quickly and at the unconscious. The display must also include the

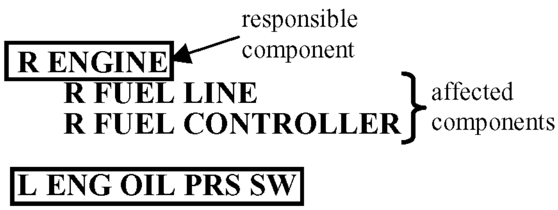


Figure 3 – Propagation of Faults

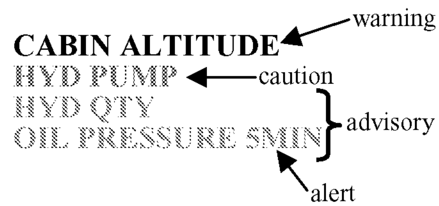


Figure 4 – Predictive Alerting Message

relationships between components within the system as is currently done on overhead control panels in aircraft. Additional relationships between systems would also be of benefit during propagating failures[8] (fig. 3).

III.C. Alerts

If there is a problem, the crew must be notified as to the severity, the function directly affected, and its affects on the overall mission. The aerospace industry has done research on alerting schemes[9,10] and on notifying the crew of system-failure affects on the mission.[11,12] Typically, alerts are split into warnings, which indicate immediate crew action is needed; cautions, which indicate crew action will be needed; and advisories, which indicate information the crew needs to know but no action is required.

Parallel research exists within the nuclear power industry with alert displays that respond in a manner consistent with individual processing schemes. As in aviation, the first order of business is to make sure everything is under control. This requires a control area designed around confined spaces, protection equipment and sensor detectors for radiation leaks, escape routes, lockdown procedures, and clean up, maintenance and repair protocols and procedures. This is doubly important to long-term space flight because of the confined environmental space within the vehicle.

While alerts typically trigger when a parameter has reached a predefined limit, other research has indicated that flight crews would like to have predictive capabilities before an alert range is actually reached since it would give them more time to deal with the anomaly.[13,14] Basically, this predictive information would notify the operators that a parameter is trending to an alert range. The predictive information would help with maintaining performance and situation awareness while keeping workload low since problems could be taken care of in a more thorough manner before time compressed immediate action is required. This predictive capability would be aided by the displays developed along the lines of biofusion where the human is the receiver of the information using hardware displays as augmented systems for cursory monitoring if those displays showed deviations from normal expected values like E-MACS and MSG do. The traditional alerting display may also be used to show predictions[13,14] (fig. 4). In any case, procedures need to be developed in order to ensure the crew uses the predictive information in the most beneficial manner.

III.D. Procedures

Typically, for each alert there is an associated procedure. This is true for both aircraft and nuclear power plants. As with monitoring, these checklists could have varying degrees of automation. The current aircraft checklist automation used is demonstrated in the Boeing 777[15] with guidelines suggested by the Federal Aviation Adminstration.[16]

In order to complete a procedure, operators must understand the situation. With automation, this awareness will decrease leading to a performance decrease. This performance degradation most likely will manifest itself in the speed the operators are able to remedy the non-normal situation especially for complex checklists. It will be compounded if the displays do not reflect how the operators normally process information.

Thus, such platforms as wireless computers that simulate PDAs could be used by a crewmember who is cerebrally connected via biofusion to the main system. This direct connection yields two immediate benefits. First, the information would always be available to the crewmember no matter where he is located. Second, the information can be tailored to each crewmember.

III.E. Detailed Diagnosis and Repair

If time permits, the crew will be able to accomplish a more detailed diagnosis and thorough repair of the non-normal situations. This will necessitate the need for knowledge acquisition about the operation of the craft and systems. This area may benefit from electronic libraries, wireless computers, and 3D displays. 3D bio-interactive displays would allow for realistic rehearsal of repairs before the actual repair is done since the unconscious does not distinguish reality from fiction. The simulation could also be used to judge the effectiveness of different solutions.

IV. SYNTHESIS OF AIRCRAFT AND SPACECRAFT

IV.A. Shuttle Technology

Fortunately, there has been some work on combining the display knowledge from the aircraft industry to spacecraft. An example of this is the shuttle's avionics upgrade. This upgrade is looking at modernizing the primary flight display and trajectory displays.[17] These displays are exploiting the use of color and much improved memory and processing speeds now available. Testing of these displays during nominal and off-nominal situations indicate an improvement in workload, situation awareness, and performance.[18]

IV.B. Nuclear-Powered Space Missions

Putting the aforementioned aspects together, the power plant controls for a nuclear enabled space mission will be a conglomeration of flight deck displays and nuclear power plant control rooms such that the dual function of piloting and power plant operation is feasible. The addition of 3D displays tailored to each crewmember will allow for the crewmember to process vast amounts of information in a timely manner.

V. CONCLUSIONS

We will have to look beyond the standard conventional means of designing human-interactive systems to approaches such that the human can sense the problem via biofusion input, and respond to the situation via adaptive systems. This is critical because of the amount of information that can be accessed by the crew due to computers and highly sensored vehicles. This proliferation of information will not necessarily increase performance and situation awareness. Performance and situation awareness will only be optimized once the appropriate function allocation between human and computer is achieved.

ACKNOWLEDGMENTS

Oak Ridge National Laboratory, which is operated by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.

REFERENCES

1. K. COWLING, "NASA's Budget: Back to the Future – and to Basics," *SpaceRef.com* (Feb 5, 2002).
2. M. T. PALMER, W. H. Rogers, H. N. Press, K. A. Latorella, and T. S. Abbott, *A Crew-Centered Flight Deck Design Philosophy for High-Speed Civil Transport (HSCT) Aircraft*, NASA-TM 109171 (1995).
3. D. B. KABER, *Levels of Automation in the Commercial Aircraft Cockpit and Pilot Situation Awareness*, NASA Langley Research Center Grant No. NAG-1-01002 Final Report (2002).
4. T. S. ABBOTT and W. H. Rogers, "Functional Categories for Human-Centered Flight Deck Design."
5. T. S. ABBOTT, *Task-Oriented Display Design: Concept and Example*, NASA-TM 101685 (1989).
6. T. S. ABBOTT, *A Simulation Evaluation of the Engine Monitoring and Control System Display*, NASA-TP 2960 (1990).
7. A. C. TRUJILLO, "Mission Status Graphics: A Quick Look at How You Are Doing," *Poster session presentation at the Human Factors and Ergonomics Society 2000 Triennial Congress* (2000)
8. P. C. SCHUTTE and A. C. Trujillo, "Pilot Fault Management Performance: An Evaluation of Assistance," *Proceedings of the 3rd Automation Technology and Human Performance Conference* (1998).
9. G. P. BOUCEK, D. A. Po-Chedley, B. L. Berson, D.C. Hanson, M. F. Leffler, and R. W. White, *Aircraft Alerting Systems Standardization Study: Volume I – Candidate System Validation and Time-Critical Display Evaluation*, DOT/FAA/RD-81/38/I (1981).
10. B. L. BERSON, D. A. Po-Chedley, G. P. Boucek, D.C. Hanson, M. F. Leffler, and R. L. Wasson, *Aircraft Alerting Systems Standardization Study: Volume II – Aircraft Alerting Systems Design Guidelines*, DOT/FAA/RD-81/38/II (1981).
11. T. L. CHEN and A. R. Pritchett, "Cockpit Decision Aids for Emergency Flight Planning," *Journal of Aircraft*, **Vol. 31**, *No. 5*, pp. 935-943 (2001).
12. T. L. CHEN and A. R. Pritchett, "Impact of Cockpit Decision-Aids for the Task of Emergency Flight Planning," Presented at the *AIAA Guidance, Navigation, and Control Conference*, Montreal PQ, Canada (2001).
13. A. C. TRUJILLO, "Changes in Pilot Behavior with Predictive System Status Information," *Proceedings of*

the 10th International Symposium on Aviation Psychology (1999).

14. A. C. TRUJILLO, "Pilot Mental Workload with Predictive System Status Information," *Proceedings of the 1998 4th Annual Symposium on Human Interaction with Complex Systems*, pp. 73-80 (1998).

15 D. BOORMAN, "Today's Electronic Checklists Reduce Likelihood of Crew Errors and Help Prevent Mishaps," *ICAO Journal*, **1**, pp. 17-20 & 36 (2001)

16 D. C. CHANDRA, *Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags (EFBs) Version 1: Basic Functions*, pp. 57-76, FAA, DOT-VNTSC-FAA-00-22, Washington, D.C. (2000)

17. FLIGHT SPACE DEVELOPMENT TEAM FOR THE SPACE SHUTTLE COCKPIT COUNCIL, *Block 1 Avionics Upgrade: Primary Flight Display and Orbit Trajectory Display Dictionary* (2000).

18. B. HILTY and S. Lindsey, *Space Shuttle Upgrade Program: Flight Crew Workload/Performance Margin Assessment*, NASA-Ames.

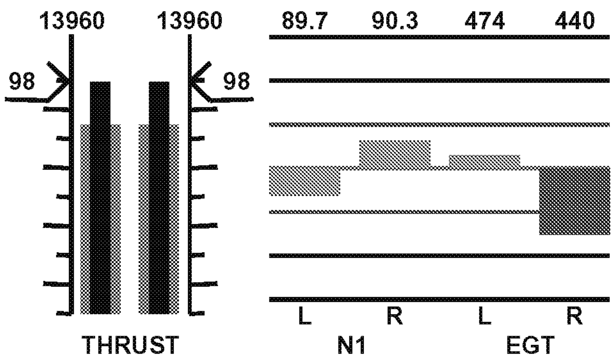
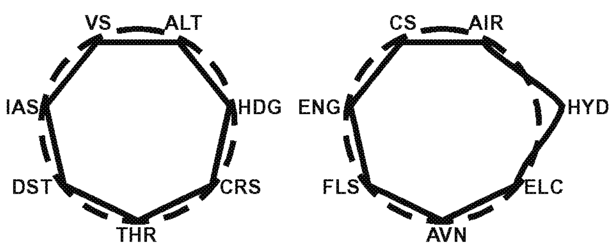


Figure 1 – E-MACS Display



ALT = altitude
HDG = heading
CRS = course
THR = thrust
DST = distance
IAS = indicated air speed
VS = vertical speed

AIR = pneumatic system
HYD = hydraulic system
ELC = electrical system
AVN = avionics
FLS = fuel system
ENG = engine
CS = control surfaces

Figure 2 – MSG Display

Table I – Information Processing Order

Information Acquisition Order	Number of Pilots	%
Visual – Auditory – Kinesthetic	10	48%
Auditory – Visual – Kinesthetic	6	28%
Kinesthetic – Visual – Auditory	3	14%
Visual – Kinesthetic – Auditory	2	10%

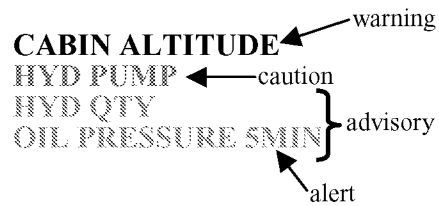


Figure 4 – Predictive Alerting Message

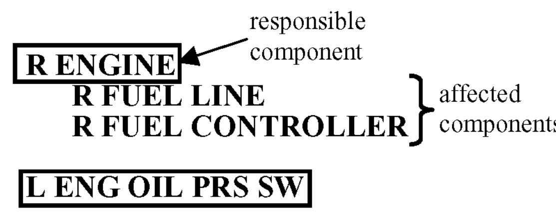


Figure 3 – Propagation of Faults